Efficient, Switching-Free Buck and Boost Conversion for RF Circuits

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An enhanced linear regulator technology retains the low noise, simplicity and low component count advantages of a linear regulator while achieving much higher efficiency and offering boost capability. A comparison between conventional switching and linear DC voltage regulators in a demanding variable-voltage attenuator application is presented.

DC voltage regulators are indispensable components in practically all modern electronics. Their job is to convert inputs from DC power sources into precise, stable and specific DC voltages required by system components. The input may be from an unregulated DC source, such as a battery, or from a mismatched-voltage source, such as an upstream AC/DC or DC/DC converter. The importance of their role in electronic systems is difficult to overstate — an enormous range of semiconductor chips, from basic to cutting-edge, depend on these devices for a stable, controlled source of DC power.

Building the next generation of RF systems that are smaller, lighter and higher performance than ever before places extraordinary demands on the specifications of voltage regulators. They are required to have minimal size, weight and component count; high conversion efficiency; low electromagnetic interference (EMI); and, for space applications, resilience to harsh radiation and temperature environments. However, a significant capability gap exists in technologies capable of simultaneously meeting these requirements, leading to multiple design trade-offs. The unique technology presented here aims to bridge this gap with an innovative photon-enhanced regulator approach.

For decades, electronics designers have faced a fundamental trade-off between three critical factors in power management designs:

- **Noise**: Switching regulators are highly efficient but generate significant conducted and radiated EMI emissions — a major pain point in noise-sensitive circuits.
- **Efficiency**: Linear regulators (LDOs) provide clean power but are highly inefficient for anything other than very small voltage steps, generating excessive heat and wasting battery life. Also, LDOs can only step down voltage, which limits their usefulness.
- **Size**: Switching regulators are bulky, requiring many additional passive components. To mitigate noise, they require extensive use of filtering components and designers commonly use sprawling, two-stage solutions comprising a switching regulator followed by an LDO. This trade-off inflates the bill of materials (BoM), increases the physical footprint and complicates thermal management.

The limitations of conventional voltage regulators are addressed with an enhanced linear regulator (ELR) architecture. This approach combines the inherent advantages of linear regulators — simplicity, minimal component count and intrinsically low noise — with the efficient voltage conversion capabilities typically associated with switch-

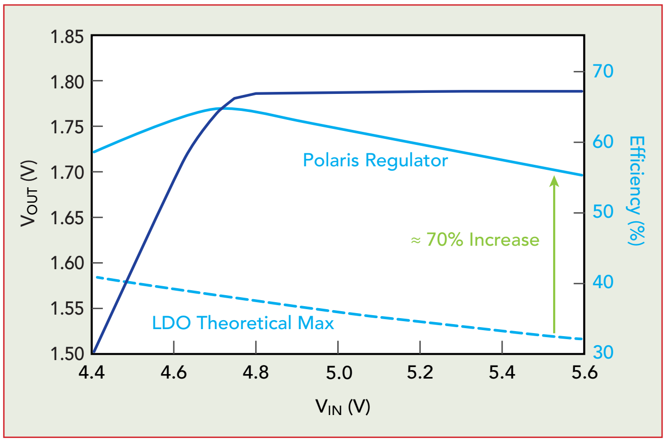

Fig. 1 **Efficiency and output of ELR BK291D18V with 200 mA load current.[1] Efficiencies roughly 70 percent greater than the theoretical limit for LDOs are possible with this device.**

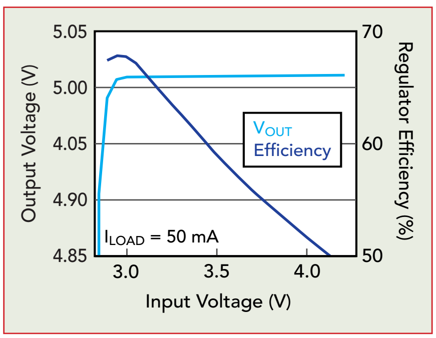

Fig. 2 **Efficiency and output of ELR BT291D50M — a high efficiency, switching-free DC boost voltage regulator.[1] The device is configured for a regulated 5 V output.**

ing regulators. The architecture far exceeds the theoretical efficiency limits of linear regulators while avoiding the noise-generation drawbacks present in switching-regulator designs.

By delivering both step-down and boost capabilities, ELRs provide a versatile solution for power management in noise-sensitive systems. For space applications, radiation-tolerant variants maintain these performance advantages in high-radiation environments.

The operation of ELRs and their application in an extremely noise-sensitive, footprint-constrained variable-voltage attenuator circuit are described here. Greatly improved noise performance with reduced input current compared to a linear regulator is demonstrated.

ENHANCED LINEAR REGULATORS

The ELR architecture comprises a conventional Si-based LDO co-packaged with unique, high performance, GaAs-based photovoltaic-output optocouplers in a multi-chip module. The role of optocouplers is to convert power normally wasted in conventional linear regulators into useful output power by efficiently transferring optical power from the LED section to the photovoltaic devices. The optocouplers have unprecedented efficiencies exceeding 52 percent (defined as power out of the photovoltaic versus power into the LED). More detail on their performance and design, along with a description of the operating principles of ELRs, is provided by Lumb et al.[1]

When integrated into a novel circuit, optocouplers achieve 60 to 90 percent voltage-regulator efficiency, depending on the step size, and deliver much higher efficiency than conventional LDOs for large voltage steps. This is shown in ***Figure 1*** for a ≥ 5 V to 1.8 V buck regulator.[1]

The high efficiency optocouplers also enable efficient boost regulators without switching. This exploits the ability of photovoltaic-output optocoupler devices to transform voltage, resulting in purely linear boost conversion, free from the ripple issues present in conventional boost regulators.

An example of a ≥ 3 V to 5 V boost converter is shown in ***Figure 2***. This unique circuit topology has much greater efficiency than previous attempts at switching-free boost conversion.[2]

BK300D50E VOLTAGE REGULATOR

In this work, a regulator is required that can step down from ≥ 12 V to ≤ 5 V with high efficiency and extremely low output noise. To meet these specifications, BK300D50E was developed. This device uses five GaAs optocouplers and an LT3045 chip — an extremely low noise LDO from Analog Devices.[3]

Each of the series-connected PV devices generates roughly 1 V at maximum power, resulting in a chip that can output up to 5 V. The chips are co-packaged in a 7 by 7 mm^2 QFN32 package that has excellent thermal properties and a very compact footprint. All the additional features of LT3045 are retained, including power-good feedback, current limiting and enable/disable functionality. ***Figure 3*** shows a simplified block diagram of the device. Connecting the BYP pin to the IN pin bypasses the LED array, allowing the device to operate as a conventional LDO if required.

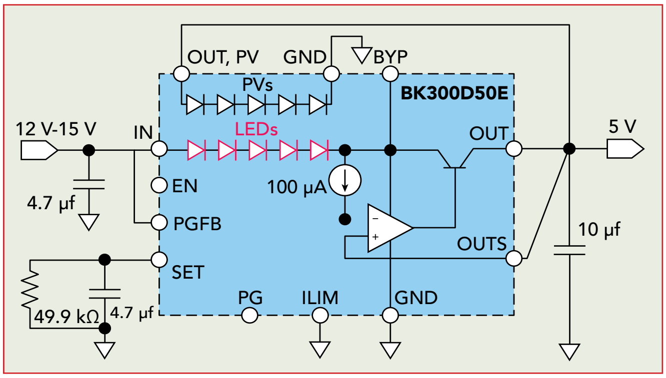

Fig. 3 **Simplified block diagram and application. Power-good and current limit functionalities are not used in this example.**

Figure 4 shows the input current of the regulator with a 13 V input, a 5 V output and a 100 mA load. Input current is dramatically lower for the ELR compared to a conventional LT3045 LDO over the same step, resulting in significantly lower parasitic power loss and reduced device heating.

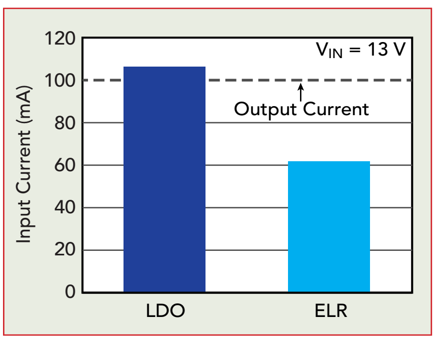

Fig. 4 **Input current required to supply 100 mA load, comparing the ELR against an LDO's performance.**

BK300D50E retains the exquisite power integrity of LT3045. Output noise remains below 1 µVRMS (see ***Figure 5***), and spot noise is approximately 2 nV/√Hz at 10 kHz. Power supply ripple rejection exceeds 120 dB — including greater than 75 dB at 1 MHz (see ***Figure 6***). This unique combination of ultra-low noise, high efficiency and small footprint makes BK300D50E an ideal candidate for demanding voltage-variable attenuator (VVA) applications.

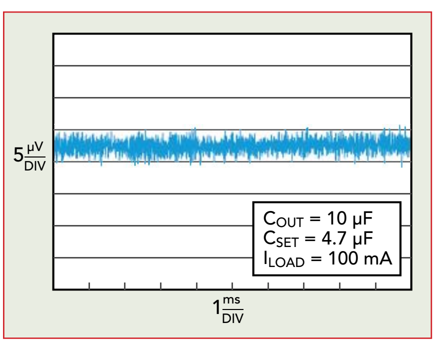

Fig. 5 **Output voltage noise time series with 100 mA load current.**

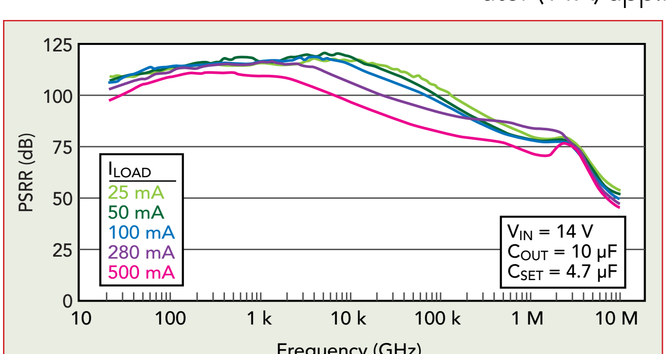

Fig. 6 **Power supply ripple rejection at different load currents.**

VOLTAGE-VARIABLE ATTENUATOR

VVAs are critical components in modern RF systems, providing precise signal level control for applications ranging from electronic warfare to telecommunications test equipment. As system performance requirements advance, designers face increasing pressure to achieve wider dynamic range while maintaining compact form factors and low power consumption.

At high attenuation levels — when the VVA reduces signal strength by 60 dB or more — even minute power supply artifacts can dominate the output spectrum. A switching regulator's inherent ripple and harmonic content, no matter how well filtered, can manifest as discrete spurs that exceed the attenuated signal amplitude. In this regime, what registers as negligible noise in many applications becomes the limiting factor in achievable dynamic range.

In the present application, a switching regulator operating at 15 V input requires a maximum input current of 115 mA. Still, spurious signals from the regulator are observed on the RF carrier output. Transitioning to an all-linear regulation approach eliminates spurs but comes at a steep cost, drawing 300 mA from the supply and causing excessive heating. The footprint associated with a high efficiency switching regulator followed by a low-dropout linear post-regulator to suppress switching artifacts is prohibitive, and even with this approach, switching spurs can persist at levels incompatible with a 100 dB dynamic range target.

ELR technology offers a path forward. By combining the inherent noise advantages of linear regulation with a photon-enhanced efficiency architecture, BK300D50E eliminates switching spurs while drawing only 165 mA, thereby maintaining near-switching-level efficiency. This directly enables a > 30 dB improvement in system dynamic range, as shown in a spectrum analyzer measurement of an RF carrier, where the system is powered by a switching regulator versus the ELR (see ***Figures 7***a and 7b).

Equally important for product development cycles, the ELR's drop-in compatibility with standard LDO design practices eliminates the EMC design complexity associated with switching regulators and significantly reduces the power management BoM.

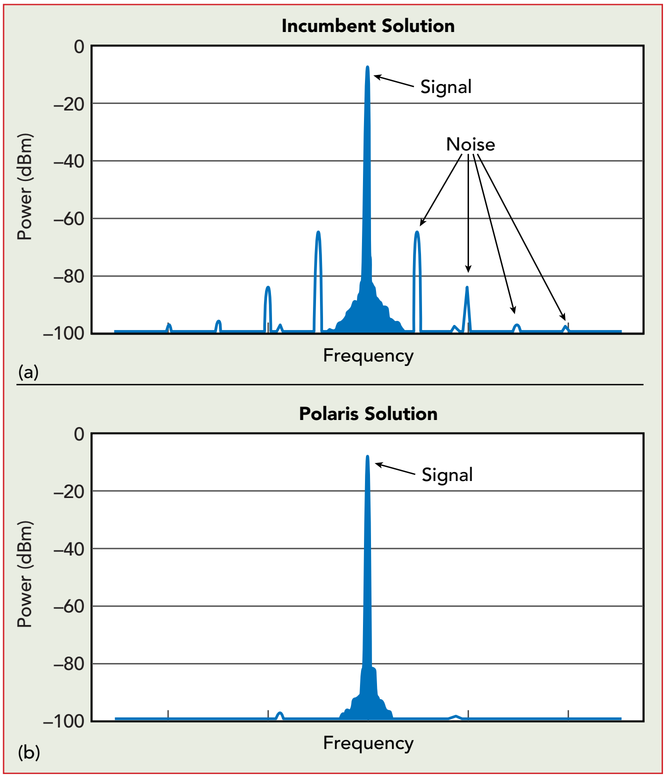

Fig. 7 **Spectrum analyzer measurements of an RF carrier output using a switching regulator incumbent solution (a) and an ELR (b).**

CONCLUSION

ELRs are a promising solution to solve difficult power management challenges in highly noise-sensitive electronics. The performance of a high efficiency 12 V/5 V switching-free buck converter is described, offering near-switching-level efficiency and extremely low output noise, with an application to a cutting-edge VVA circuit. ■

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